

# Solid state Pomeranchuk effect

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## Abstract

Recently we have shown that  $YbInCu_4$  and related compounds present a solid state Pomeranchuk effect. These systems have a first order volume transition where a local moment phase coexists with a renormalized Fermi liquid in analogy with  $^3He$  at its melting curve. We demonstrate here experimentally that the solid state Pomeranchuk effect, controlled by a magnetic field, can be used to produce cooling.

*Key words:* Kondo lattice, Pomeranchuk effect

The system  $^3He$  along its melting line presents the unusual feature that the entropy of the liquid is smaller than that of the solid [1]. This is the basis of the Pomeranchuk effect [1] which has an important application as a cooling mechanism and played a central role in the discovery of the superfluid phases of  $^3He$  [1]. It was generally believed that this is a unique property of this extremely quantum system. Recently, we have shown that  $YbInCu_4$  and related compounds also present a solid state Pomeranchuk effect [2,3]. This is best shown in Fig. 1 where at the first order volume transition temperature,  $T_V \approx 42$  K, a local moment phase, indicated by the Curie-Weiss susceptibility, coexists with a renormalized Fermi liquid with a nearly temperature independent susceptibility, such as along the melting line of  $^3He$ . An external magnetic field shifts the volume instability to lower temperatures according to a law of corresponding states [4,5]. This can be derived from the magnetic Clausius-Clapeyron equation,

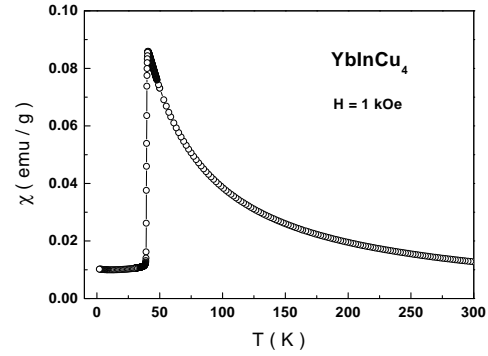


Fig. 1. Magnetic susceptibility of  $YbInCu_4$  as a function of temperature measured in a field of 1 kOe. At  $T_V \approx 42$  K Fermi liquid and local moment phases coexist.

$$\left(\frac{dT}{dH}\right)_{H_V} = \frac{-(M_{LM} - M_{FL})_{H_V}}{(S_{LM} - S_{FL})_{H_V}} \quad (1)$$

At the coexistence line the magnetization of the local moment phase is much larger than that of the Fermi liquid ( $M_{LM} \gg M_{FL}$ ). Also, assuming that the entropies in the distinct phases satisfy the relation  $S_{LM} \gg S_{FL}$ , we get

$$\left(\frac{dT}{dH}\right)_{H_V} = \frac{-M_{LM}}{S_{LM}}$$

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where  $M_{LM} = \chi H = (C/T)H$  and  $C$  is the Curie constant. Substituting in the equation above and integrating yields,

$$H_V^2 = 2 \frac{S_{LM}}{C} B - \frac{S_{LM}}{C} T_V^2$$

but for  $T = 0$

$$H_V^2(T_V = 0) = 2 \frac{S_{LM}}{C} B = H_0^2$$

such that,

$$\frac{H_V^2}{H_0^2} = 1 - \frac{T_V^2}{T_0^2}. \quad (2)$$

This is the *circular law of corresponding states* [4,5] with  $T_0 = \sqrt{C/S_{LM}} H_0$ . Since  $C = g_J^2 J(J+1) \mu_B^2 / 3k_B$  and taking  $S_{LM} = k_B \ln(2J+1)$  [5], we find

$$k_B T_0 = g_J \mu_B H_0 \sqrt{\frac{J(J+1)}{3 \ln(2J+1)}}.$$

This yields for the ratio

$$\frac{k_B T_0}{\mu_B H_0} = \frac{g_J \sqrt{J(J+1)}}{\sqrt{3 \ln(2J+1)}} = \frac{4.5}{\sqrt{3 \ln 8}} = 1.80 \quad (3)$$

in excellent agreement with the experimental result for this ratio (1.8) [4,5]. We used  $J = 7/2$ . Since  $T_0 = 42$  K [4], the zero temperature critical field  $H_0 = 34.7$  T in agreement with the scaling result [4].

Fig. 2 shows the entropy of the Fermi liquid and local moment phases for an external field  $H_V = 4.9$  T, such that  $T_V(H_V) = 0.99 T_0$  [3]. The entropy of the FL phase is obtained from the coefficient of the linear term of the specific heat  $\gamma = 50$  mJ/mol K<sup>2</sup> [4]. This figure illustrates how cooling can be produced by adiabatically applying a magnetic field to the sample in the FL phase and transforming it to the LM phase. In Fig. 3 we present the results of a preliminary experiment. The sample temperature under a quasi-adiabatic application of an external magnetic field, sweeping from 0 to 9 T, was measured for a single crystal of  $YbInCu_4$  (grown as described previously in Ref. [4]). In this experiment we used the heat capacity option setup of a Quantum Design Physical Properties Measurements System (PPMS). In this setup, the sample is placed on a wired platform coupled to a temperature sensor and kept under high vacuum. The sample was zero-field-cooled to a given temperature near  $T_V$  and its temperature was measured while the magnetic field was varied from 0 - 9 T at  $\sim 100$  G/min. The cooling effect can be clearly observable in the data but it is not of the expected magnitude. This data provides unambiguous evidence for the existence of the Pomeranchuk effect in  $YbInCu_4$ . At the moment, the magnitude of the effect might be somewhat limited by the employed experimental conditions. The theoretical expectation is for

a larger effect. Further experiments are in progress to confirm this.

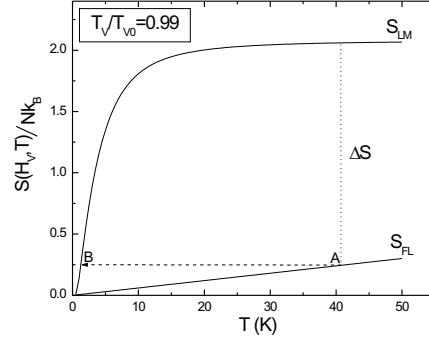


Fig. 2. Entropy of the local moment (LM) and Fermi liquid phases (FL) of  $YbInCu_4$  at a field  $H_V$ , such that,  $T_V(H_V)/T_V(0) = 0.99$  [3]. The isentropic process from A to B reduces the temperature of the system

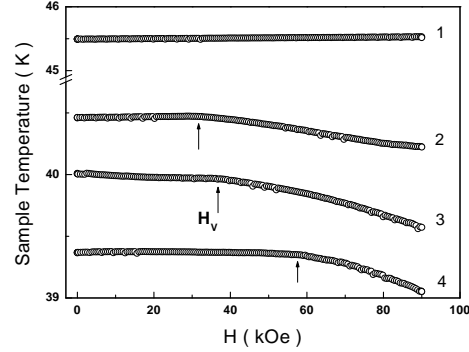


Fig. 3. Temperature of the sample under a quasi-adiabatic application of an external magnetic field.

We have shown that the solid state Pomeranchuk effect in  $YbInCu_4$ , can be controlled magnetically and used to produce cooling.

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